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Constraint on Lorentz Non-Invariance From the Michel Parameter

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ABSTRACT

It is pointed out that the Michel parameter can be used to put a limit on a class of Lorentz non-invariant interactions.

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The idea that Lorentz invariance is a low energy phenomena has recently been advanced by Chada-Nielsen and by Nielsen-Ninomiya [1]. Starting with a suitable non-covariant model of electrodynamics, these authors show, by explicit calculation of the relevant β function, that this model simulates Lorentz invariance better and better as the energy scale is lowered.

Using the "simplest and most predictive model," Nielsen-Picek [2] explored the experimental conditions under which Lorentz non-invariant interactions (L.N.I.) could be observed in the decay of leptons and pseudoscalar particles (π, k). They concluded that the analysis of μ total decay rate is almost insensitive to L.N.I. effects, and that there are better possibilities of testing Lorentz invariance in charged pion and kaon decays.

The purpose of this note is to study the angular distribution of μ-polarized decay $\mu \to e\nu\bar{\nu}$, in the presence of Lorentz non-invariant interactions. In particular, we analyze the information that can be obtained from the precise measurements of μ decay parameters.

A convenient way of introducing L.N.I. is to allow a Lorentz nonscalar coupling of the Higgs to the gauge boson.

$$g^{\mu\nu}(D_\mu\phi)(D_\nu\phi)^\dagger \to h^{\mu\nu}(D_\mu\phi)(D_\nu\phi)^\dagger \tag{1}$$

This results in an effective current-current interaction [2]

$$H_{eff} = \frac{G}{\sqrt{2}} (g^{\mu\nu}+x^{\mu\nu}) (J^{\dagger}_{\mu}(x) J_{\nu}(x) + h.c.) \tag{2}$$

Where, if the deviation from Lorentz invariance is assumed to be rotational invariant then

$$x^{oo} = \alpha \qquad x^{ii} = \frac{\alpha}{3} \quad , \tag{3}$$

and so α is a measure of the breaking of Lorentz invariance. We will assume that the weak interactions are described by the standard model [3] so that the charged currents are pure V-A. Then a straightforward calculation using the effective interaction eq. (2) show that the differential decay rate for completely polarized μ in its rest frame is given by[f1]

$$\frac{1}{\Gamma} \frac{d\Gamma}{dx\,d(\cos\theta)} = x^2 \{ (3-2x)(1-a_1\cos\theta) + \alpha(2-\frac{8}{3}x)(1+a_2\cos\theta) \}$$

$$a_1 = \frac{2x-1}{3-2x} \qquad a_2 = \frac{1}{3-4x} \quad , \tag{4}$$

where as usual $x=E/E_{max}$, E is the energy of the electron and θ is the angle between the μ polarization and the outgoing electron momentum. The idea now is to compare eq. (4) with the usual parametrization.[4]

[f1] Corrections of the order $(M_e/M_{\mu})^2 \sim 10^{-5}$ to the eq. (4) have been neglected.

$$\frac{1}{\Gamma}\,\frac{d\Gamma}{dxd(\cos\theta)} = x^2\Big\{(3-2x) + (\frac{4}{3}\rho-1)(4x-3) + 12\,\frac{M_e}{xM_\mu}\,(1-x)\eta$$

$$+ [(2x-1)+(\frac{4}{3}\delta-1)(4x-3)]\xi p_\mu\cos\theta\Big\} \tag{5}$$

This leads us to the relations[f2]

$$\rho = \frac{3}{4} - \frac{\alpha}{2} \qquad \delta = \frac{3}{4} + \frac{\alpha}{2} \quad , \tag{6}$$

the present values of these parameters are. [5]

$$\rho = 0.7518 \pm 0.0026 \qquad \delta = 0.755 \pm 0.009 \tag{7}$$

To obtain a value for α, we will only use the more accurately known Michel parameter ρ.

$$\alpha = (3.6\pm5.2)\times10^{-3} \quad . \tag{8}$$

This is a similar limit as that obtained by Picek and Nielsen from the existing data on π and k decays, $\langle\alpha\rangle = (0.54\pm0.17)\times10^{-3}$.

However, what makes the Michel parameter interesting is the fact that a presently running experiment [6] will certainly allow us to improve the constraint on α. From the expected [6] experimental error in ρ, we find $\alpha\leq2.3\times10^{-4}$.

[f2] To obtain the relation between δ and α, it is necessary to integrate over energies. Furthermore, we have taken ξ=1.

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